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VECTOR ALGEBRA*

BY A. MACFARLANE, D.SC., LL.D.

This brief contains a statement of the principles which were demonstrated and applied.

The quantities of common algebra may be viewed not only as scalars, that is, ratios, but also as vectors having a common space-unit. By *vector-algebra* is meant the generalisation which is obtained when the elementary vectors are supposed to have different directions. A sum of such terms as $A + B + C$ is no longer represented by a single straight line, but by a bent line made up of straight portions.

NOTATION.—Elementary vectors will be denoted throughout this article by italic capitals as A, B, C; their moduli by the corresponding small italics as a, b, c; and their space-units by the corresponding Greek letters as α, β, γ.

The Terms are Successive

A sum of such terms is a vector binomial, trinomial, or polynomial, and it has properties depending on the order of the terms; hence these are not in general commutative. The resultant is independent of the order, but the enclosed area is not.

Logical Harmony

As vector-algebra is a generalisation of the common algebra, all its results are logically harmonious with the results of common algebra, and where the vectors have the same direction, the principles of common algebra still apply.

Rules for Addition and Multiplication

When the principle of succession is applied to addition as well as to multiplication, the rules obtained for addition are analogous to those for multiplication. For instance:

* Brief of five lectures on Vector Algebra delivered at the University of Toronto, 10 to 14, Feb. 1913.

In addition	In multiplication
$A + B$, not $= B + A$	AB, not $= BA$
$A - A = 0$	$A\ {}^1/_A = 1$
$-A + A = 0$	${}^1/_A\ A = 1$
$A + B - B = A$	$A\ B\ {}^1/_B = A$
$A + B - A$ not $= B$	$A\ B\ {}^1/_A$ not $= B$
$A + B + A$ not $= 2\ A + B$	$A\ B\ A$ not $= A^2\ B$
$2\ (A + B) = 2\ A + 2\ B$	$(A\ B)^2 = A^2\ B^2$
$\frac{1}{2}\ (A + B) = \frac{1}{2}\ A + \frac{1}{2}\ B$	$(A\ B)^{\frac{1}{2}} = A^{\frac{1}{2}}\ B^{\frac{1}{2}}$

Principle of Double Multiplication

When a vector is expressed in terms of a modulus and space-unit, any function of the vector is equivalent to the same function of the space-unit multiplied by the corresponding function of the modulus. For example; if $R = r\rho$, and $S = s\,\sigma$; then $R^2 = r^2\rho^2$, $RS = rs\rho\,\sigma$, ${}^1/_R = {}^1/_r \cdot {}^1/_\rho$, $\log R = \log r \log \rho$. By vector analysts it is commonly held that the reciprocal of a vector involves only the reciprocal of the modulus, where as the above principle holds that it involves the reciprocal of the space-unit also.

Components of a Binary Product of Vectors

$BC = Cos\ BC + i\ Sin\ BC$. The former, called the scalar component, has the modulus $bc\ cos\ \beta\gamma$, and the unit β^2. The latter, called the vector component, has the modulus $bc\ sin\ \beta\gamma$ and the unit $[\beta\gamma]$, which has two dimensions in length, and the i is properly an index of $[\beta\gamma]$. This equation states the fundamental principle of quaterinous.

Square of Vector Binomial

$(B + C)^2 = B^2 + 2BC + C^2$ not $B^2 + BC + CB + C^2$.

The scalar component is $B^2 + 2\ Cos\ BC + C^2$, and the vector component $2i\ Sin\ BC$.

Binomial Theorem for Vectors, n Being Integer Number

$(B + C)^n = B^n + nB^{n-1}\ C + \ldots\ldots + C^n$.

When n is odd, the whole expression is vector; when n is even it breaks up into a scalar and a vector component. The same formula is true for n being a rational number, or negative.

Square of Trinomial of Vectors

$(A + B + C)^2 = A^2 + B^2 + C^2 + 2AB + 2AC + 2BC$.

The modulus of the scalar component gives the square of the modulus of the resultant, namely, $a^2 + b^2 + c^2 + 2\ ab\ cos\ \alpha\beta + 2\ ac\ cos\ \alpha\gamma + 2\ bc\ cos\ \beta\gamma$. The vector component,

$2i\ (Sin\ AB + Sin\ AC + Sin\ BC)$ gives four times the resultant of the enclosed area.

Principle of Differentiation

The differential quotient of R^n is $\frac{dR^n}{dR}$; the reduced value of which is the differential coefficient. The formula for finding the latter is $\frac{dR^n}{dR} = \mathcal{L}_{\Delta R = o} \left\{ -R^n + (R + \Delta R)^n \right\} \frac{1}{\Delta R}$; which, by the Binomial Theorem, gives nR^{n-1} for the differential coefficient; and this whether n is integral or fractional, positive or negative.

Differential of a Product of Vectors

It follows that $d\,(RS) = RdS + SdR$, the differential being subsequent in either term; also $d(R + S)^2 = 2(R + S)\,(dR + dS)$.

Taylor's Theorem

It follows from the rule for obtaining the differential coefficient of a power that Taylor's Theorem retains its form, provided only the intrinsic order of the factors is preserved.

Principle of Integration

Being the converse of the principle of differentiation, it is

$$\int R^n\, dR = \frac{1}{n+1}\quad R^{n+1}.$$

The expression $\int dR$ means the resultant of all the infinitesimal vectors between two points of a space curve, it is the chord of the curve, when the origin is on the curve.

Notation for a Spherical Angle

Let β denote a unit axis of the sphere, and b an angle in circular measure; then B^b denotes b radians round the axis β. Both β and b are of zero dimension. Hence $\beta^{\overline{\frac{\pi}{2}}}$ denotes a quadrant round β, and β^1 one radian round β.

Exponential Expression for a Spherical Angle

Since $\log \beta^b = b \log \beta^1$ and $\log \beta^1 = \beta^{\overline{\frac{\pi}{2}}}$ we derive $\beta^b = e^{b\beta^{\overline{\frac{\pi}{2}}}}$. This is Euler's expression for a circular angle extended to a spherical angle.

Extension to Space of Euler's Principle that

$$e^{ib} = cos\ b + i\ sin\ b.$$

By the exponential theorem

$$e^{b\beta^{\overline{\frac{\pi}{2}}}} = 1 + b\beta^{\overline{\frac{\pi}{2}}} + \frac{1}{2!}\ b^2\,\beta^{\pi} + \frac{1}{3!}\ b^3\,\beta^{3\overline{\frac{\pi}{2}}} +$$

$$= 1 - \frac{b^2}{2!} + \frac{b^4}{4!} -$$

$$+\left\{b-\frac{b^3}{3!}+\frac{b^5}{5!}-\right\}\beta^{\frac{\pi}{2}}$$

$$=\cos b+\sin b\,\beta^{\frac{\pi}{2}}.$$

Rule for the Composition of Two Quadrants on the Sphere

Let $\beta^{\frac{\pi}{2}}$ and $\gamma^{\frac{\pi}{2}}$ denote the two quadrants. In the standard case, where the angle between β and γ is less than a quadrant

$$\beta^{\frac{\pi}{2}}\gamma^{\frac{\pi}{2}}=-\cos\beta\gamma-\sin\beta\gamma\left[\beta\gamma\right]^{\frac{\pi}{2}}$$
$$=\left[\beta\gamma\right]^{\pi}+<\beta\gamma.$$

The resultant has the axis $\left[\beta\gamma\right]$ and is greater than two right angles by the angle between the axis. Hamilton makes it the complementary angle instead of the supplementary, but in doing so he takes the negative angle. As a consequence his vector term is positive while his scalar term is negative.

Hamilton's Fundamental Rules

These are usually stated in terms of a set of orthogonal axes i, j, k; but to avoid conflict with the use of i to denote $\sqrt{-1}$, it is here replaced by h. These axes are best viewed as of zero dimension. There are three distinct sets of rules according as both factors are vectors, one a quadrant and the other a vector, or both quadrants.

First: both factors vectors,

$$\begin{array}{lll} [hj]=k, & [jk]=h, & [kh]=j \\ [jh]=-k, & [kj]=-h, & [hk]=-j \\ [hh] & [jj] & [kk] \end{array}$$

The polar axis of h and j is k, that of j and h is $-k$; that of $[hh]$ is any axis normal to h. There is one choice; we can make $[hj]=k$ denote the relation of the right handed screw, or the relation of the left handed screw. The former is now commonly adopted.

Second: first factor a quadrant, second a vector,

$$\begin{array}{lll} h^{\frac{\pi}{2}}j=k, & j^{\frac{\pi}{2}}k=h, & k^{\frac{\pi}{2}}h=j, \\ j^{\frac{\pi}{2}}h=-k, & k^{\frac{\pi}{2}}j=-h, & h^{\frac{\pi}{2}}k=-j, \\ h^{\frac{\pi}{2}}h=h, & j^{\frac{\pi}{2}}j=j, & k^{\frac{\pi}{2}}k=k. \end{array}$$

These rules apply to the rotation of a line. A quadrant round h changes j into k, while one round j changes h into $-k$. This set of rules must be logically harmonious with, although they are not identical with the first set.

Third: both factors quadrants

$$h^{\frac{\pi}{2}} j^{\frac{\pi}{2}} = -k^{\frac{\pi}{2}}, \quad j^{\frac{\pi}{2}} k^{\frac{\pi}{2}} = -h^{\frac{\pi}{2}}, \quad k^{\frac{\pi}{2}} h^{\frac{\pi}{2}} = -j^{\frac{\pi}{2}},$$

$$j^{\frac{\pi}{2}} h^{\frac{\pi}{2}} = k^{\frac{\pi}{2}}, \quad k^{\frac{\pi}{2}} j^{\frac{\pi}{2}} = h^{\frac{\pi}{2}}, \quad h^{\frac{\pi}{2}} k^{\frac{\pi}{2}} = j^{\frac{\pi}{2}},$$

$$h^{\frac{\pi}{2}} h^{\frac{\pi}{2}} = [hh]^{\pi}, \quad j^{\frac{\pi}{2}} j^{\frac{\pi}{2}} = [jj]^{\pi}, \quad k^{\frac{\pi}{2}} k^{\frac{\pi}{2}} = [kk]^{\pi}.$$

Here we have the composition of quadranted angles; all of these rules are special applications of the above rule for the composition of two angles; even the last three, which are indefinite.

Composition of Two Spherical Angles

$$\beta^b = \cos b + \sin b \,.\, \beta^{\frac{\pi}{2}}$$

$$\gamma^c = \cos c + \sin c \,.\, \gamma^{\frac{\pi}{2}} \quad \text{therefore}$$

$$\beta^b \gamma^c = \cos b \cos c + \cos c \sin b \,.\, \beta^{\frac{\pi}{2}}$$

$$+ \cos b \sin c \,.\, \gamma^{\frac{\pi}{2}} + \sin b \sin c \, \beta^{\frac{\pi}{2}} \gamma^{\frac{\pi}{2}}$$

The fourth term is found from the composition of quadrants.

$$-\sin b \sin c \left(\cos \beta\gamma + \sin \beta\gamma \,.\, [\beta\gamma]^{\frac{\pi}{2}}\right)$$

Hence $\beta^b \gamma^c = \cos b \cos c - \sin b \sin c \cos \beta\gamma$

$$+ \left\{\cos b \sin c \,.\, \gamma + \cos c \sin b \,.\, \beta - \sin b \sin c \sin \beta\gamma \; [\beta\gamma]\right\}^{\frac{\pi}{2}}$$

Development of the Resultant in Terms of the Component Angles

$$\beta^b \gamma^c = e^{b\beta^{\frac{\pi}{2}}} e^{c\gamma^{\frac{\pi}{2}}}$$

$$= e^{b\beta^{\frac{\pi}{2}} + c\gamma^{\frac{\pi}{2}}}$$

$$= 1 + \left(b\,\beta^{\frac{\pi}{2}} + c\gamma^{\frac{\pi}{2}}\right) + \frac{1}{2!}\left(b\,\beta^{\frac{\pi}{2}} + c\,\gamma^{\frac{\pi}{2}}\right)^2 + \text{etc.}$$

The powers of this binomial are expanded after the same formula as the corresponding powers of a binomial of vectors: for instance,

$$\left\{b\,\beta^{\frac{\pi}{2}} + c\,\gamma^{\frac{\pi}{2}}\right\}^2 = b^2\,\beta^{\pi} + 2\,b\,c\,\beta^{\frac{\pi}{2}}\gamma^{\frac{\pi}{2}} + c^2\,\gamma^{\pi}$$

$$= -\left(b^2 + c^2 + 2\,b\,c \cos \beta\gamma\right) - 2\,b\,c\left[\beta\gamma\right]^{\frac{\pi}{2}}.$$

Here we have applied to space logarithms the principle that the log of the product is the sum of the logs of the factors.

Notation for a Hyperbolic Angle

The equilateral-hyperbolic angle is derived from the circular angle β^{b} by inserting $\frac{1}{i}$, that is $-i$, before b, hence we get β^{-ib}.

$$\text{Hence } \beta^{-ib} = \cos\left(-i\,b\right) + \sin\left(-i\,b\right)\beta^{\frac{\mu}{2}}$$

$$= \cosh b + \frac{1}{i}\sinh b \,.\, \beta^{\frac{\pi}{2}}.$$

By $\beta^{\frac{\pi}{2}}$ is now meant the elliptic quadrant between the transverse and the congregate axis.

Exponential Expression for a Hyperbolic Angle

The exponential expression is $e^{-ib}\,\beta^{\frac{\pi}{2}}$. It is to be noted that the $-i$ and the index $\frac{\pi}{2}$ cancel in a way, giving $\frac{b}{\beta}$, which expression corresponds to the common imperfect expression for a hyperbolic angle, namely, e^{b}.

Composition of Two Equilateral Hyperbolic Angles

$$\beta^{-ib}\,\gamma^{-ic} = \left(\cosh b + \frac{1}{i}\sinh b \,.\, \beta^{\frac{\pi}{2}}\right)\left(\cosh c + \frac{1}{i}\sinh c \,.\, \gamma^{\frac{\pi}{2}}\right) = \cosh b \cosh c + \frac{1}{i}\left(\cosh b \sinh c \,.\, \gamma^{\frac{\pi}{2}} + \cosh c \sinh b \,.\, \beta^{\frac{\pi}{2}}\right) - \sinh b \sinh c\, \beta^{\frac{\pi}{2}}\,\gamma^{\frac{\pi}{2}}.$$

The last term is reduced as before: hence the hyperbolic cosine of the resultant is $\cosh b \cosh c + \sinh b \sinh c \cos \beta\gamma$; and the hyperbolic sine is $-i \cosh b \sinh c \,.\, \gamma^{\frac{\pi}{2}} \; -i \cosh c \sinh.\ b\, \beta^{\frac{\pi}{2}} + \sinh.\ b \sinh.\ c \sin \beta\gamma\, [\beta\gamma]^{\frac{\pi}{2}}$. As the last term is not affected by $-i$, the sine is that of a general hyperbolic angle.

These principles were applied in the last lecture to the theory of relativity.

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THREE-PHASE TRANSFORMATION

By Chas. H. Russell, B.A.Sc.

In the following article the writer does not intend to go into the design of transformers, or their mechanical construction, but will deal with their uses, and the advantages and disadvantages of the different types and arrangements.

If we look into the fluxes demanded by three sine wave electromotive forces, displaced from each other by 120 electrical time degrees, we will see that at any instant the sum of any two of the fluxes is equal in value and opposite in direction to the remaining flux. The meaning of this result is that if a transformer core be constructed with three legs, each wound with the same number of turns, and if the three windings be subjected to electromotive forces in true three phase relation to each other, each coil and core will operate exactly like the primary winding and magnetic circuit of a separate single-phase transformer. Therefore by increasing the material of a core-type single-phase transformer by slightly more than 50 per cent., the rating of the equipment becomes exactly 50 per cent. greater, as a three-phase transformer. Thus by adding a little over 50 per cent. to the material of a 10 kilowatt core-type transformer, there is obtained a three-phase transformer whose rating is 15 kilowatts. Such a poly-phase transformer is capable of performing the work of three 5 kilowatt single-phase transformers delta-connected or Y-connected, or of two 8.66 kilowatt transformers V-connected, or of one 7.5 kilowatt and one 8.66 kilowatt transformers T-connected.

When transforming from one three-phase to a second three-phase circuit either of several arrangements of transformers may be employed as follows:

(1) Three single-phase transformers connected in delta or in star.

(2) One three-phase transformer with windings connected in delta or in star.

(3) Two single-phase transformers connected in V or T.

As the transformers required in either of the above arrangements may be placed in one case with three primary and three secondary terminals, the unit may be termed a three-phase transformer in a general sense. In so far as their practical use is concerned, the three arrangements are essentially the same. If, however, the magnetic and electrical characteristics of the transformer be taken into account there are marked differences between the several methods.

When transforming three-phase power it is necessary that there shall be magnetic fluxes of two or three different phases. When three single-phase transformers are used the magnetic fluxes in the different transformers have a phase difference of 120° respectively. When two single-phase transformers are used, the phase difference depends on the method of connection and may be either 90° or 120°. In the real three-phase transformer there are three magnetic fluxes which are different in phase, but these fluxes are not limited to separate and

independent cores as in the above arrangements. In the three-phase transformer there are certain parts of the core which may carry the fluxes of two or of all three of the magnetic circuits. As the resultant of two or three magnetic fluxes which are out of phase with one another is less than their arithmetical sum, it follows that there is a certain saving in material by arranging the magnetic circuits so that certain parts of the core carry the magnetic fluxes of more than one of the magnetic circuits.

There are also other economies in using a single three-phase transformer instead of using two or three smaller ones of the same aggregate output. These will be dealt with later.

The construction of the three-phase transformer follows the general forms in use for the single-phase transformer and may be either core or shell-type. The general appearance of a common core type is shown in Figure 1. It consists of three cores of equal cross

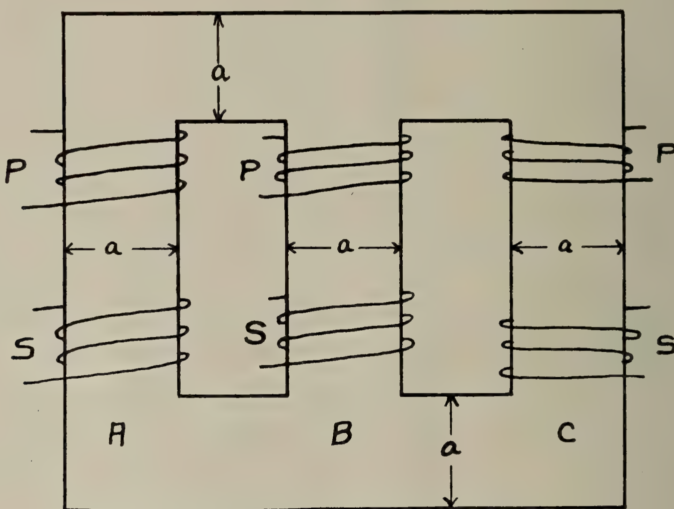


Fig. 1.

section joined by a common top and bottom yoke of the same section as each core, and upon each core are placed the primary and secondary windings for one phase. The coils on the three cores are connected so that the fluxes in the cores are 120 degrees apart, making their algebraic sum zero at any instant. The relation of the fluxes is shown in Fig. 2, which shows that there is 120 degrees difference between the time that the flux in A is a maximum in one direction until that in B and in C becomes a maximum in the same direction, and it will be seen that when the flux in it is a maximum in one direction, it is balanced by fluxes in B and C in the opposite direction. When we have a three-phase transmission system we know that three wires are sufficient for carrying the three-phase currents, so in a three phase transformer three cores are sufficient for carrying the three-

phase fluxes. In a three-phase transmission system if the mutual induction between any two circuits is to be the same, the three wires are arranged in the form of an equilateral triangle, but for the sake of simplicity, the three wires are often placed in the same straight line. It is similar in a three-phase transformer, when the mutual magnetic relations between the three phases are to be identical, the three cores are arranged in triangular form. But it is found that by properly proportioning the transformer, the three cores may be placed in the same line with but a small departure from symmetrical relations. This arrangement gives a better and cheaper mechanical construction and is therefore the one most commonly adopted. If a short-circuit occurs in any phase of a core-type transformer, such as the type shown in Fig. 1, the whole transformer will be rendered useless for transforming three-phase currents, as the resultant flux from the two operating phases will be driven through the short-circuited coils, and cause an excessive current to flow in the windings. However, if one phase is short-circuited, the transformer may be operated single-phase by

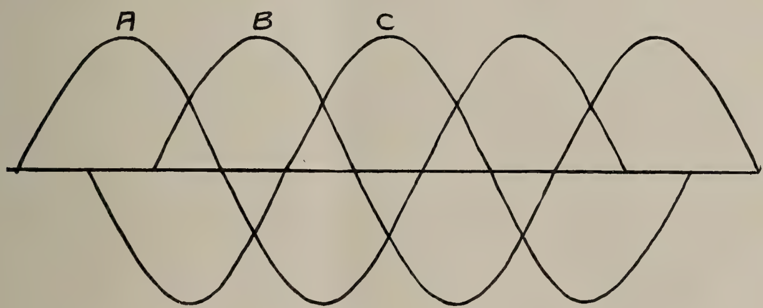


Fig. 2.

connecting the two undamaged phases just as if the short-circuited coil were removed. If one phase is open-circuited, the two remaining phases may be reconnected in V or in T for transforming from three-phase to three-phase; or the windings may be connected in series on in parallel for single-phase transformation.

For small transformers the cost per kilowatt decreases rapidly, and the efficiency increases rapidly, with the increase in size.

If we look at Fig. 3, we can see the relative increase in constructive material required for changing a single-phase transformer to a three-phase transformer having a 50 per cent. larger rating. There will be an increase of 50 per cent. in the copper used and the iron must be increased by slightly more than 50 per cent. At an average value, it may be stated that the weight of copper per kilowatt rating will be about 6% greater than, and the weight of copper exactly the same as, that for a single-phase transformer having 66 2-3 per cent. as large a rating.

Using values obtained from certain commercial lines of single-phase core-type transformers, it is found that the copper of a 10 kilowatt transformer weighs 17.3 pounds per kilowatt and the iron

weighs 22 pounds per kilowatt, while the corresponding values for a 5 kilowatt are 23.6 pounds of copper and 25.6 pounds of iron. Thus a 15 kilowatt three-phase transformer requires 17.3 pounds of copper and 25.6 pounds of iron per kilowatt, while three five kilowatt single-transformers require 23.6 pounds of copper and 25.6 pounds of iron per kilowatt. Moreover, the copper loss in the three phase transformer at full load is 17.7 watts, and the iron loss 11.2 watts per kilowatt while the corresponding losses for the three single-phase transformers are 20 and 12.2 watts respectively. Thus the full load efficiency of three-phase transformer is 97.2 per cent. and of the three single-phase transformers 96.9 per cent.

If curves were plotted of "weight in pounds per kilowatt" over "total capacity in kilowatts" it would be seen that for each value of power to be transformed, the three-phase transformer requires less constructive material and is more efficient than three single-phase transformers having the same combined total rating. But it must

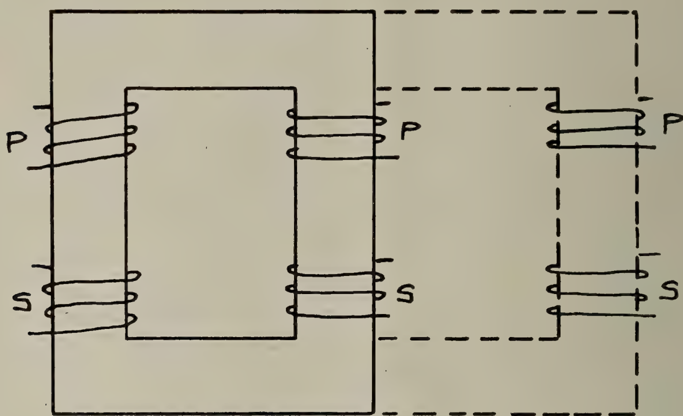


Fig. 3.

be noted that a single-phase transformer of the same total rating requires much less material and is more efficient than the three-phase unit.

These facts deal with the fundamental phenomena involved in the design of transformers, and they are independent of the decrease in manufacturing cost with the increase in size of transformer units. The last mentioned decrease emphasizes the relative advantages of the three-phase transformer; it is more pronounced in small units because the cost approximates a constant value per pound of material for extremely large transformers, but approaches more nearly a constant value per transformer units in very small size.

Although in selecting the material and determining the dimensions of any certain line of transformers the designer arranges each unit as a compromise between the demands of lightness and efficiency, quite independent of the other units of the same line, the fact remains that the best compromise for each unit is so related that for the other

units that there results a definite rate of decrease of loss, or of weight, per kilowatt with increase in capacity of the transformers of each line.

A study of numerous lines of single-phase transformers as manufactured at the present time shows that the loss in watts per kilowatt in any line of transformers may be expressed with an error that is quite small by the following equation:

$$L = \frac{k}{W^x}$$

Where W is the rating of the transformer in any chosen unit, k is the loss in watts per kilowatt for a transformer rated at one unit, and x is the exponent, the value of which varies slightly with the rating but is practically constant over a large range. It has been found that for almost all lines of transformers, including core type and shell-type, high-voltage and low-voltage, high frequenc and low-frequency, air blast, self cooling and water cooled, x has a value seldom much greater or less than .26; it is larger at low ratings and also at very high electromotive forces. The meaning of this result is that the loss in a 3 kilowatt transformer is three fourths as large per kilowatt as that in a 1 kilowatt transformer of the same line; the loss per kilowatt in a 30 kilowatt transformer equals 75 per cent. of that in a 10 kilowatt transformer, a 300 kilowatt transformer has a loss per kilowatt three-fourths of that of a 100 kilowatt transformer, and a 3000 kilowatt transformer suffers a loss of 75 per cent. as large per kilowatt as that of a 1000 kilowatt transformer and so on.

In any certain line of transformers the core loss per pound of iron and the coil loss per pound of copper do not vary appreciably throughout a limited range in rating; that is the magnetic and current densities are constant; yet the ratio of iron to copper changes somewhat with the size of the transformer. Thus two transformers having exactly the same loss per pound of iron and per pound of copper, and the same total loss per kilowatt, may not weigh the same per kilowatt; moreover, the constructive material may not cost the same per kilowatt of rating or per pound of total weight. However, throughout a limited range it may be fairly stated that the weight of transformers in a certain line varies directly with the losses.

It might be well to compare the advantages of one-phase and three-phase transformers. Of course, when considering the relative advantages of three-phase and single-phase transformers it will be assumed that the three-phase transformer is to be compared with a group of three one-phase transformers whose aggregate output is the same as that of one three-phase transformer; for it will be admitted at once that a comparison between one single-phase transformer and one three-phase transformer of the same output would be all in favor of the one-phase transformer.

On this assumption, the advantages of the three-phase transformer over the one-phase are as follows:

1. Lower cost.
2. Higher efficiency.

3. Less floor space and less weight.
4. Simplification in outside wiring.
5. Reduced transportation charges and reduced cost of installation.

The disadvantages are:
1. Greater cost of spare units.
2. Greater derangement of service in the event of breakdown.
3. Greater cost of repair.
4. Greater difficulties in bringing out taps for a large number of voltages.

The various advantages and disadvantages given above will be considered in detail.

Advantages

Lower Cost.

A three-phase transformer should always be cheaper to manufacture than three one-phase transformers of the same total output; for by combining one-phase units into a three-phase unit, there results a considerable saving in active material due to the magnetic phase relations. Also there is only one containing case, one set of end frames, one cooling system, etc., to be provided for the three-phase unit. The labor is also less, not only on account of there being less active material to handle in one case, one set of end frames, etc., but because the unit as a whole is larger, and there is always less labor cost in manufacturing one large unit than there is in manufacturing several smaller units for the same total output.

All things considered, the cost of a three-phase transformer may be taken as about 85 per cent. of that of three one-phase transformers, the total capacity, frequency and voltage being the same in the two cases.

Higher Efficiency.

Since there is less active material in the three-phase transformer than in the one-phase group, the loss at the same densities will be less, and therefore the efficiencies higher, consequently the total radiating surface required will be less. The losses of a three-phase transformer are 16.5 per cent. less than three single-phase transformers of the same aggregate output.

Less Floor Space and Less Weight

By using a three-phase transformer there is about 30 per cent. floor space saved, and usually its height is somewhat less than the one-phase type. The weight of the three-phase transformer is also 16.5 per cent. less than three separate transformers.

Simplification in Outside Wiring

The star or delta connection of a three-phase transformer is simply and easily made inside the case, for, as a rule, only three

high tension and three low tension leads are brought out; whereas with three one-phase transformers, at least six high tension and six low tension leads are brought out and the transformers interconnected by suitable wiring.

Reduced Transportation Charges and Reduced Cost of Installation.

The lighter weight and less bulk of the three-phase transformer will, in general, result in reduced transportation charges, especially where shipment is made by water. This advantage is open to question, however, when there are long wagon hauls over rough roads, with poor facilities for handling heavy machinery. In this case it may be cheaper to transport a greater weight and bulk in small units; but in general the transportation charges should be considerably in favor of the three-phase transformer. It should also be noted that in many foreign countries duties are charged according to weight of material, but whether duties are charged according to weight or price, the advantages are with the three-phase transformer.

In general, it will be cheaper to instal one large unit than three small ones. This is particularly true when the transformer must be dried out on site by heating or by vacuum process. But for overhead work, a small three-phase transformer does not offer any saving over three one-phase transformers in cost of installation. The weight of a 60, 75, or 90 kilowatt three-phase transformer is so great that it is awkward to handle, whereas three 20, 25 or 30 kilowatt one-phase transformers can easily be hung in the ordinary way without the construction of any elevated platform; hence the total cost is no greater for three one-phase units. Also in underground work a 60 or 75 kilowatt three-phase transformer requires a special manhole cover, as it is too large for the standard size.

Disadvantages

Greater Cost of Spare Unit

It is known that any three-phase unit having three times the capacity of a one-phase unit will cost considerably more. This may be of some importance where there is but one three-phase unit, but it will be found that in many cases the cost of two three-phase transformers with a total capacity of 200 per cent. will be but little more than that of four one-phase transformers having a total output of 133 per cent. Where there are several similar three-phase units it will be found that the reduced first cost of adopting three-phase units will more than pay the difference in cost between the three-phase and the one-phase spare unit, In addition, there is the advantage that the three-phase spare unit will have three times the capacity of the one-phase spare unit.

It should be well to note, however, that with a three-phase or one-phase core type transformer, there is much less need of carrying a complete spare unit than with the shell type one-phase or three-phase transformer. This is on account of the very simple construc-

tion of the core type transformer and the ease with which it may be repaired. The top yoke is built up in one solid piece and bolted with butt joints to the three vertical cores. Thus it is necessary in case of repairs to loosen only a few nuts, remove the top yoke, slide off the damaged coils, and replace them with new ones; bolt down the yoke and replace the transformer in position. Should the laminations be welded together, it might be necessary to do considerable filing, but in general, there is less chance of burning the laminations than with the shell type of construction. With a supply of spare coils, any ordinary burn out should be repaired in a few hours. Over in Europe it is quite customary to use core type three-phase transformers with only coils as spares, even for very important work; for it has been found in actual practice that repairs can be made in but little more time than is required to replace one transformer by another.

With the present standard shell type construction a much longer time is required for repairs on account of the fact that the laminations must be removed and replaced a few at a time. The repair of a three-phase shell type transformer is a very serious operation and it would probably seldom be attempted on site, but would be returned to the manufacturer.

Greater Derangement of Service in the Event of Breakdown

When three one-phase transformers are connected in delta on both high and low tension windings, one of the three may fail and be cut out, and the remaining ones will continue to carry about two-thirds the total load without overheating. With the star connection on either winding, this cannot be done. A three-phase core type transformer cannot be operated with a short circuit on any phase. The three-phase shell type transformer may be operated, however, with a short-circuit on one-phase, provided both windings are in delta; but while this may be used as a temporary expedient for carrying partial loads, the whole transformer must be removed eventually for repairs.

In any case, whether core or shell type transformers are used, there will probably be a somewhat greater delay in substituting a three-phase spare unit than in substituting a one-phase spare unit.

Greater Cost of Repair

With three one-phase units it is probable that in the case of a breakdown in one, it will be cut out before the others are damaged. With a three-phase unit, where the phases are so near together, there is the possibility that a breakdown in one-phase may damage one or both or the others. In such a case, there are two or three phases instead of one to repair, but in any event, the repair of a three-phase transformer will be in general, more expensive than a one-phase transformer of the same type.

Reduced Capacity Obtainable in Self-Cooling Three-Phase Units

There are some cases where it is desirable to use only self-cooling transformers: about 1,500 kilowatts is approximately the maximum

size of a three-phase transformer that, with present methods of construction, can be made self-cooling. A group of three one-phase self-cooling transformers can be built with an output of two or three times this amount. Thus, if an output greater than 1,500 kilowatts is required, it will be necessary to use two three-phase transformers, a more expensive arrangement than three single-phase transformers. It is very seldom, however, that an output greater than 1,500 kilowatts is required from a self-cooling transformer. When artificial cooling is permissible, the three-phase transformer may be built for any desired capacity.

Greater Difficulties in Bringing Out Taps for a Large Number of Voltages

The increased difficulty in arranging the three-phase transformer for a larger number of different voltages might, in some cases, pre-

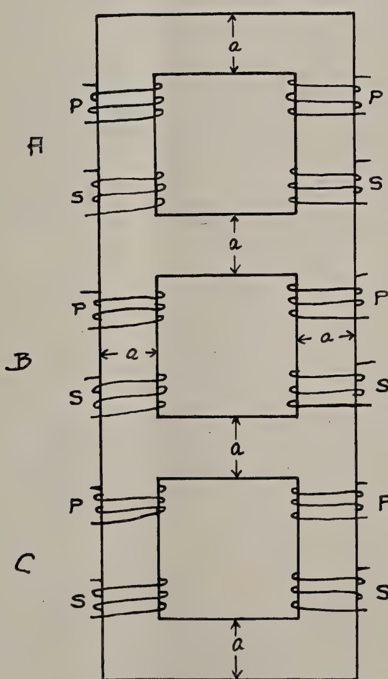


Fig. 4.

vent its use, but such cases will be of very rare occurrence and need scarcely be considered.

It may be said that the three-phase transformer has certain real and positive advantages over the one-phase type, while its disadvantages are chiefly those which result in the case of a breakdown, an

abnormal condition which is becoming rarer and rarer as the art of transformer design and manufacture improves.

In order to obtain a three-phase core-type transformer, which will not be entirely disabled when one-phase is short-circuited and in which the unbalancing in voltage produced by unequal loads on the three-phases will be eliminated, various modifications of the construction shown in figure 1 have been proposed. One of these is shown in Fig. 4. It will be seen that it consists of three single-phase transformers, placed one above the other with the section of core between two openings equal to that at all other parts of the circuits. This equal section for the part common to the fluxes of two-phases is possible on account of the fact that these fluxes are 120 degrees apart, with a resultant equal in amount to one of them Comparing this transformer with three single-phase transformers, it will be noticed that the only gain is that due to a slight saving for the iron core,

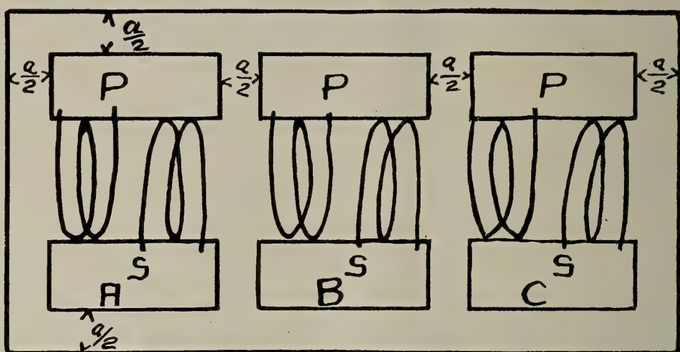


Fig. 5.

possible on account of the reduced section in that part of the magnetic circuit common to two phases. But this saving is small in comparison with the total cost of the transformer; and to offset this gain there is a loss due to its more difficult mechanical construction, as well as to the extra provisions which must be made for the cooling of the three transformers placed one above the other.

For units of small size, the core-type of construction is well adapted; but for large units, the shell-type possesses many advantages both electrical and mechanical. It is for this reason used for three-phase transformers of large size. The most common form of shell-type is shown in Fig. 5, which consists essentially of three single-phase transformers placed side by side, as shown in Fig. 6, with the section between opening of two phases reduced from "a" with single-phase transformer to one-half "a" with the three-phase transformer. This reduction in section is made possible by the fact that the windings of the different phases are so connected that the fluxes in that portion of the magnetic circuit common to two phases are 120 degrees apart, so that their resultant is equal to one of them. In this respect, it will be noted that the shell-type transformer is similar to the core-

type of construction in Fig. 1. The reduction in the amount of iron required for the magnetic circuit amounts in general to from 10 to 20 per cent. of the total iron in the transformer, and as the iron is but one of a large number of items which enter the cost, the total saving over three single-phase units is very small. The actual saving in iron is, however, not so great as it appears, for when the three cores are combined into one, the internal cooling of the transformer becomes far more difficult, and the large ventilating ducts, and clearances practically offser the gain made by the common core. There is, however, a substantial saving in cost resulting from the use of one case instead of three, but this disappears if three single-phase transformers are mounted in one case.

In general, the three-phase shell-type and core-type have the same disadvantages, while the advantages of less cost and higher efficiency for the three-phase core-type, practically disappear in the case of the three-phase shell-type, leaving reduced floor space

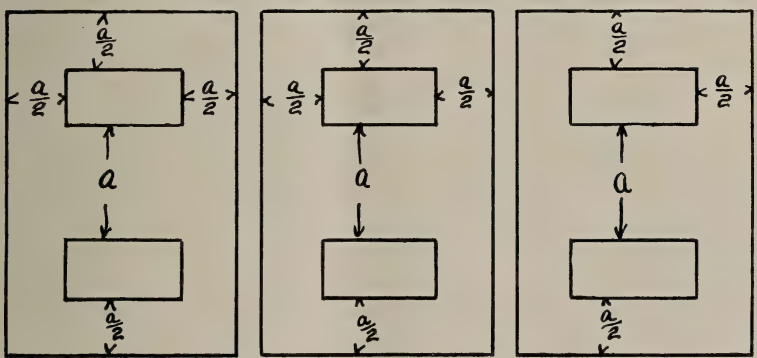


Fig. 6.

and simplicity of connections as the only advantages which may be urged in favor of this three-phase transformer. It would seem that with the three-phase limbed core transformer, there is a very substantial saving in cost over three single-phase core-type transformers, but with the core-type transformer shown in Fig. 4, the saving is extremely small. Similarly with the three-phase shell-type transformer, the reduction in cost is almost insignificant.

In the above discussion, the three-phase transformer has been compared with three one-phase transformers, but it is possible, however, to use two transformers V or T connected for transforming from three-phase to three-phase. Each transformer must have a capacity of 15 per cent. greater than half that of the total amount of power to be transformed. The cost per kilowatt of these units will be considerably less than that of the small units. If the two transformers be placed in a single case, there will result a very substantial saving in cost over three single-phase transformers or over one three-phase transformer. Two transformers V-connected weigh exactly the

same as three separate single-phase transformers for the same power transmitted; the losses are also equal. Two transformers T-connected have a combined weight 5 per cent. less than three separate transformers either delta-connected or Y-connected or than two transformers V-connected; the losses are likewise 5 per cent. less. So far as concerns the cost of the equipment and the efficiency in operation, two T-connected transformers are preferable either to two transformers delta-connected or Y-connected. In comparing the T-connection with the delta or Y-connection, it is to be noted that each connection accomplishes the transformation without sensible distortion of phase relations. The T-connection allows the neutral point to be reached equally as well as does the Y-connection. The delta connection, however, is the only one capable of transforming in emergencies with one disable transformer.

With reference to its ability to maintain balanced phase relations, the T-connection is much better than the V-connection. For the starting of three-phase motors at reduced voltages, where the transformers are in use for only a small fraction of the total time, the distortion of phase relations may not be serious; but, for continuous operation, the distortion should not be permitted. For the latter condition the T-connection is preferable in every respect to the V-connection, and in many cases it should prove more advantageous than either the delta or Y-connection of three separate transformers. It is worthy of note that the best result for the T-connection of the transformers for three-phase work is met when the two transformers possess the same ratio of primary to secondary turns and a tap is brought out from the central point of one of the transformers; the two halves of both primary and secondary windings of the latter transformer should be well interspaced to prevent excessive magnetic leakage. It is not essential that the former transformer be designed for exactly 86.6 per cent. of the voltage of the latter; the normal voltage of one can be 90 per cent. of the other without producing detrimental results. Moreover, transformers designed for the same normal electromotive force and intended for V-connection can be T-connected without considerable improvement in service. The advantage of two transformers over the three-phase shell-type transformer is that the cost is less and that the two units may be made detachable, so that one can be repaired while the other is in use, or one can be returned to the manufacturer with less cost and inconvenience than with a three-phase transformer.

The following conclusions can now be drawn up:

Where it is desired to transform from three-phase to three-phase for supplying small motors, rotary converters, etc., the three-phase core-type transformer is cheaper, more efficient and more compact than a group of two or three single-phase transformers. There are, however, objections to its use, which under certain conditions, may offset the advantages which it offers.

Any three-phase transformer, which is made up of three single-phase units joined together by a common core, presents but little

gain in cost, efficiency, or compactness, over three separate single-phase units, while there are several distinct objections to its use.

For large three-phase units, the shell-type construction is commonly employed and, since this consists of three single-phase units with a common core, it has few advantages and several disadvantages over a group of three single-phase transformers.

The few advantages claimed for the three-phase shell-type transformer over a group of three single-phase transformers, are: slightly reduced cost, reduced floor space, and simplicity of connections.

The use of two single-phase transformers (sometimes called a duplex transformer when the two are mounted in the same case) is a cheaper arrangement than the three-phase transformer, requires slightly less floor space, and its connections are just as simple.

No three-phase transformer, or group of single-phase transformers can be as cheap, efficient or compact as a single phase transformer, having the same aggregate output; thus the economical use of the three-phase transformer is practically limited to that of supplying three-phase motors and rotary converters, while the single-phase transformer can almost always be used to better advantage for lighting work.

F. L. Smith, '10, is superintendent of the Queen Victoria Mine, at Nelson, B.C., for the British Columbia Copper Co.

Walter Jackson, '07, has been appointed to the position of field engineer for the Ontario Power Company, at Niagara Falls, Ont.

E. R. Williams, '11, is assistant electrometallurgist for the Northern Aluminum Co., at Shawinigan Falls, Que.

G. A. Saunders, '99, is assistant engineer in the designing offices of the Ontario Hydro-Electric Power Commission.

J. T. Johnston, '08, is hydraulic engineer of the Water Power Branch, Department of the Interior, Ottawa.

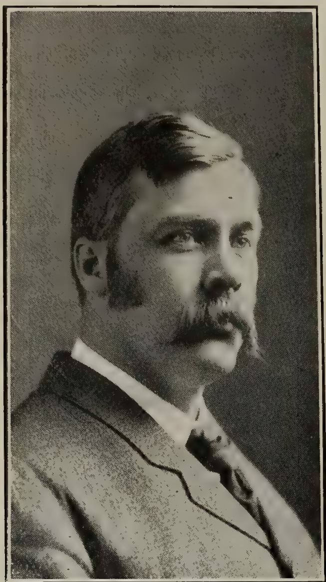
E. P. A. Phillips, '05, has accepted a position as corporation surveyor for the city of Port Arthur, Ont.

J. A. Walker, '08, is in charge of a Provincial Government Survey Party in the Fraser River Valley, B.C.

R. V. Macaulay, '11, is traffic supervisor for the Bell Telephone Co. of Canada, in the Montreal office.

BIOGRAPHY

Henry Grattan Tyrrell was born at Weston, Ontario, where he attended the public schools. He graduated in civil engineering from the School of Practical Science, receiving in 1894 a post graduate degree of C.E. from University of Toronto. He then spent a year on exploration surveys in Western Canada, and was three years in company with Mr. E. P. C. Girouard (now Sir Percy Girouard), as instrument man on railroad construction in Quebec and Maine. For several years following he was engaged as estimator, assistant engineer and later as chief engineer with different bridge and construction companies, in the design and building of bridges, buildings, and other publicworks. Then he was appointed chief engineer for the architectural firm of F. M. Andrews & Company, of Cincinnati and New York, and in 1906 was called to the Harriman Railroads as special engineer of bridges and buildings in the Western States, including Utah, California, Idaho, Nevada, Oregon, Washington and Montana. When this work was completed he was appointed engineer and western manager at Chicago for a firm of general contractors, and for them he tendered on over ten million dollars' worth of work, taking a million dollars' worth of contracts, and being the lowest bidder on another million. The contract for the Winnipeg Union Depot was awarded at his estimated cost of about $900,000. Since 1909, he has been engaged at Chicago as a consulting engineer and author.



H. G. TYRRELL, C.E., '86

In 1905, Mr. Tyrrell was employed to investigate and report on the collapse of the suspension bridge at Charleston, West Virginia, and he prepared alternate designs for rebuilding it either as a suspension or a cantilever.

While in the Western States, he made designs and plans for many structures, including concrete bridges over irrigation canals in Idaho, timber bridges and trestles on various branch lines including that to Lewiston, and alternate designs for crossing the Salmon River gorge, one of which involved a steel arch of 850 feet, with its deck 450 feet above the water. He made standard designs and estimates for reinforced concrete railway structures, including arches, culverts, trestles, viaducts, etc. (See Tyrrell's Concrete Bridges and Culverts), and re-designed many of the bridges for double track, on several hundred miles of road. He made alternate designs and plans for subways and viaducts at Ogden and Pocatello, the viaducts at Ogden

having a length of 2800 feet. Plans in masonry and metal were also made for a curved bridge over the gorge near Huntington. He reported on a water supply for the railway and town of Carlin, and planned a storage tank and distributing system.

Mr. Tyrrell then designed and superintended the construction of bridge foundations and coffer dams for a lift bridge at San Pedro harbor, the bottom of foundations being 100 feet below sea level. After the flood destruction of the railroad across Nevada to Los Angeles, he examined all the injured bridges on the road and submitted detail reports on renewing them. He visited all principal cities on the Pacific coast down into Mexico, and at San Francisco, examined the effect of earthquakes on bridges and buildings in that vicinity.

In competitions, Mr. Tyrrell designed many structures for foreign countries, including Africa, South America, Japan, China, Philippine Islands, India, etc. He was invited by the Imperial authorities of Russia to submit designs for bridging the Nava in St. Petersburg, near the winter palace of the Czar, and was also invited by the cities of Copenhagen, Denmark, and Sydney, Australia, to design bridges for those cities, that at Sydney having an estimated cost of between two and three million dollars.

Mr. Tyrrell is the inventor of improved types of movable dams, and regulating gates, and the originator of his automatic safety drawbridge gates.

The following are a few of the important works for which he was engineer:

Miami river bridge at Elizabethtown, span 586 feet. At the time the longest simple truss span in existence.

Easton, Pa., suspension bridge, length 800 feet.

Coal pockets, towers and trestles at Everett, Mass.

Middletown drawbridge, the longest highway swing span in existence.

Coal conveying plant and 500 feet gantry crane at Rouen, France.

Sinton Hotel, Cincinnati, cost $1,000,000.

Kentucky state capital at Frankfort, cost another million.

National Cash Register office building at Dayton, Ohio.

Twelve other large city buildings from nine to twenty stories.

In 1901 he made designs for a movable dam at Sault Ste. Marie, and designs for an arched cantilever bridge, 130 feet high and 1500 feet long over the Montreal river. Outline designs and estimates were also made for a bridge and structural plant, including buildings and equipment.

Mr. Tyrrell was connected with the design and construction of a great variety of other works, such as elevated railways, water towers, stand pipes, tall office and mercantile buildings, reinforced concrete and stone arch bridges, water powers, heavy masonry, retaining walls, railroad and highway bridges, traveling cranes, electric railroads, mill and industrial buildings, power plants, electric stations, car barns, machine shops, railroad terminals, coal and ore handling appliances, trestles, culverts, viaducts, subways, earth work, dams, foundations, etc. The bridges designed by him have an aggregate length of ten lineal miles and an estimated cost of $30,000,-

000, while those constructed under his designs and supervision cost $10,000,000.

His writings have appeared in forty or more technical and scientific journals of America and foreign countries, and "Tyrrell's Formulae" for the weight of bridges are well known and used generally. During the year 1913, he prepared and published reports on the comparative cost of crossing the English and Irish Channels by means of bridges and tunnels.

He is author of the following standard books: Mill Building Construction (1901), Concrete Bridges and Culverts (1909), Mill Buildings (1910), History of Bridge Engineering (1911), Artistic Bridge Design (1912), Engineering of Shops and Factories (1912), Movable Bridges (ready for press).

In 1905 he was elected vice-president of the Canadian Club of Cincinnati, and two years later he organized, and was elected the first president, of the Canadian Club of Utah. He is a member of The Western Society of Engineers, of the Society for the Promotion of Engineering Education, etc., and now resides with his family in the Chicago suburb of Evanston.

Walter J. Francis, '93, has been elected a member of the Institution of Civil Engineers.

F. S. Falconer, '09, is topographica assistant in the geological surveys branch, Department of the Interior, Ottawa.

F. R. Beatty, '07, is assistant manager of the architectural bronze and iron department of the Canada Foundry Co., Toronto.

W. B. Dunbar, '11, is with the Toronto Power Co., construction department and not on engineering work in the west, as reported in the directory.

F. J. James, '10, is engaged in prospect work at Anyox, B.C.

H. L. Batten, '11, is looking after the interests of the Consolidated Mining and Smelting Co. of Canada, Limited, Traill, B.C., at their Centre Star (Rossland) Mine.

J. Lanning, '11, is with the "Ben-my-chree" mines in Northern British Columbia, in complete charge of the company's administrative work there.

J. H. Morice, '08, is with the General Electric Company, Schenectady, N.Y., as switchboard proposal engineer.

J. L. Stiver, '07, is inspector of gas and electricity at Toronto, for the Inland Revenue Department, Dominion Government.

S. A. Wookey, '09, is field engineer, for the Dominion Mineral Exploration Syndicate, at Timmins, Ont.

E. H. Niebel, '11, until recently in the Montreal offices of the Northern Electric and Manufacturing Co., is now in the Winnipeg branch of that Company.

APPLIED SCIENCE

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EDITORIAL

THE SCHOOL AND THE BOARD

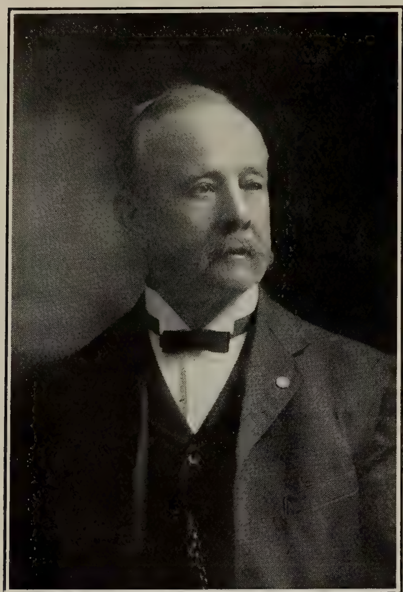
Frequent reference has been made in this journal to the accomplishments of C. H. Mitchell, C.E., of the Class of '92, and we do not suppose he would look with favor upon his biography in these pages, so we propose to postpone its appearance, that it may be more carefully perused by our readers, when hours seasoned with weather that is conducive to reading are with us again. Something which will not wait, however, is our appreciation of the fact that Mr. Mitchell was notified not long ago of his appointment to a chair on the Board of Governors of the University of Toronto.

Having a School man on the Board is something for us, as graduates and students, to thoroughly recognize. Being the first to be so chosen, is in itself a distinction which, in our estimation, is justly fitting to the graduate who has so acquired it. But of infinitely more importance is the value, to the School, of the choice. In the first place, it did not necessarily include School men in the category for

selection. Secondly, no School man was a-hunting for the appointment. So it simmers down to a like perspective in the eye of the Provincial Government as in our own. C. H. Mitchell was the man for the chair. He is not there to represent the School, or its graduates, but he is there, just the same, and years will not elapse before we feel that he is there.

"PROF." W. J. GRAHAM

Graduates of the School, and many others who honor its halls with an occasional visit, will note something queer about the institution on their next trip. Students will wander about the building next fall in search for their chief adviser and friend. The staff will note it, too. Mr. Graham, part and parcel of the institution for the past thirty-six years, is no longer associated with it. No building ever rested in more faithful charge, and since it has now parted company with one of its chief characteristics, with all due respect to his successor, we can but remark that with Mr. Graham goes many of its charms of tradition and its parental hospitality, as we used to experience them.



"PROF." W. J. GRAHAM

He is one of the few whom every reader of Applied Science has known, and what a volume of confidences and opinions he must have had thrust upon him at one time and another! Again, with all due respect to the Faculty, no one of us has ever had occasion to doubt our implicit faith in the silence of the man to whom we entrusted so many of our own personal opinions for safe and wholesome storage.

Mr. Graham closed his term of office with the month of June. Feeling the responsibilities unjustly increasing with the increase in years of service, the University authorities relieved him of his duties, with a retiring allowance of $500.00 annually.

"Prof." has not entered upon a term of holidays, however. He entered the employ of the city almost immediately, on less burdensome work, and though we will long regret his departure from College halls, we feel the lessening of arduous duties will mean a prolonged term of the remarkable health and vigor with which it is his good fortune to be in possession.

After so many years of continuous attendance to our needs, it

will seem a little unnatural for him to see October come and go beyond the horizon of drafting rooms and lecture rooms with serenity sore disturbed. So many men have entered, meekness and peacefulness in their countenances, have tackled the King Post Truss, passed into Graded Tint, forsaken Upright Egyptian, evaded the calculus and taken to the slide-rule, and finally have departed, remembered at length only in the annals, and on the walls, and oftentimes by a little episode. "Prof." Graham had them all, and few could return to find unawares an unextended hand. In the joys of autumn and terrors of spring, the feeling grew that, "Men may come, and men may go, but ——"

We hope that with him will be associated as many pleasant recollections of us, to the end of his days, as we entertain of him, and his "Five o'clock, gentlemen."

DIRECTORY OF THE ALUMNI

H (*Continued*)

Hett, S., '06, is at Le Pas, Man., as locating engineer for the Hudson Bay Ry.

Hewson, W. G., '05, is with the Hydro-Electric Power Commission of Ontario, Toronto Office, as assistant engineer.

Hewson, E. G., '08, division engineer of Ontario lines of the Grand Trunk Railway, resides in Toronto, Ont.

Hickling, F. G., '10, is in the engineering office of the Westinghouse Electric and Manufacturing Co. at East Pittsburg, Pa.

Hecks, W. A. B., '97, resides in Philadelphia, Pa.

Hill, E. M. M., '04, is in Edmonton, Alta., in the engineering department of the Canadian Northern Railway.

Hill, S. N., '04, is with the topographical surveys branch, Department of the Interior, Ottawa, Can.

Hill, H. O., '07, is designing engineer for the Blaw Steel Construction Co., Pittsburg, Pa.

Hill, H. R., '11, is in the engineering office of the Toronto Harbour Commission.

Hillis, C. R., '06, whose home is in Toronto, is consulting engineer for the Canadian Westinghouse Co., Hamilton.

Hinch, E. F., '10, is resident engineer at Port Credit, Ont., for the Toronto Power Company.

Hogarth, G., '09, is assistant engineer, Ontario Department of Public Works, Toronto.

Hogg, T. H., '07, is assistant hydraulic engineer for the Ontario Hydro-Electric Power Commission, and resides in Toronto.

Holcroft, H. S., '00, is in Toronto with the Canada Life Assurance Co.

Holmes, A. E., '09, is in Hamilton, Ont., with the Canadian Westinghouse Co.

Holmes, C. R., '09, is in Detroit, Mich., with the Electric Storage Battery Company.

Hookway, C. W., '06, is with the Canadian Allis Chalmers Co., in the Winnipeg office.

Hopkins, P. E., '10, is stationed at Porcupine, Ont., for the Ontario Bureau of Mines.

Hopkins, R. H., '06, is on the engineering staff of the University of Toronto, as lecturer in electrical engineering.

Horton, J. A., '03, was in Northern Ontario when last heard from, several years ago.

Hoshal, G. C., '09, is with the Hydro-Electric Power Commission, with headquarters at Windsor, Ont.

Houston, R. S., '06, is assistant engineer with the Vulcan Iron Works, Winnipeg, Man.

Huber, W., '06, is chief assistant engineer, York County Highway Commissions, Toronto.

Huether, D. J., '08, is demonstrator in chemistry, Faculty of Applied Science and Engineering, University of Toronto.

Huether, A. D., '08, is a member of the engineering staff of the City of Toronto, main drainage works.

Huff, A. J., '11, is in Edmonton,

Alta., with the Huff Gravel Co., Limited.

Huffman, K., '11, whose home is in Toronto, is with Mackenzie, Mann & Co., construction department.

Hughes, C., '09, is location engineer for the St. John & Quebec Railway, with the Fredericton, N.B., office.

Hull, H. S., '95, was with the Cambria Steel Co. in their works at Johnstown, Pa., as structural engineer, when last heard from.

Hull, A. H., '06, is assistant electrical engineer in the Toronto office of the Ontario Hydro-Electric Power Commission.

Hunter, A. E., '09, is on survey work in the Peace River District of Western Canada.

Hunter, A. N., '08, is demonstrator in the electrical engineering department, Faculty of Applied Science and Engineering, University of Toronto.

Hutcheon, J., '90, who for a number of years was engaged in civil and municipal engineering at Guelph, is now on the staff of the Department of Lands, Forests and Mines, Toronto.

Hutton, C. H., '07, is with the Dominion Power Co., of Hamilton, Ont., as electrical engineer.

Hyatt, H., '11, is assistant engineer for P. Lyall & Sons, on the construction of their brick plant at Cooksville, Ont.

Hyland, H. M., '07, is a member of the Hyland Construction Co., railroad contractors, and is at present on construction work near Belleville, Ont.

Hyman, E. W., '07, lives in London, Ont., where he is assistant superintendent of the London Electric Co.

I.

Iler, S. B., '08, is construction engineer on transmission line and substation work at Belleville, Ont., for the Electric Power Co.

Ingles, C. J., '04, whose home is in Toronto, is resident engineer on the Healey Falls power development.

Innes, W. L., '90, is general manager of the Dominion Canners Limited plants at Simcoe, Ont.

Ireland, L. G., '07, is manager of the Brantford Hydro-Electric System, Brantford, Ont.